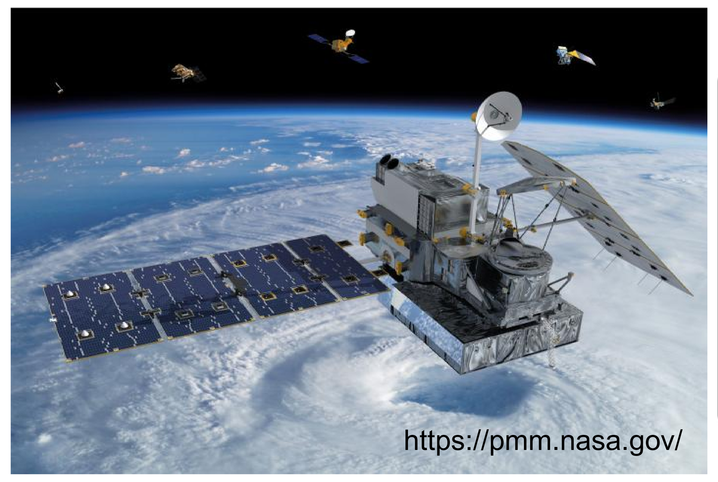

Development of a 3-D radiative transfer code for assessing multiple scattering impacts on the GPM/DPR measurements

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Context

The Japanese National Institute of information and Communications Technology (NICT) has a long experience for developing and exploiting microwave and millimeters active and passive sensors (λ=1 cm–0.1 mm). These sensors have the capability to see through clouds proving information on the internal physical properties.

The Precipitation Radar (13.8 GHz) of the TRMM mission (1997-2015, NASA/JAXA) provided essential precipitation data, and its successor, the Dual Precipitation Radar (13.6 and 35.5 GHz) of the GPM mission (2014-) is continuing the observations with better sensitivity and additonal data from the use of the Ka-band (35.5 GHz).

The cloud profiling radar of the Earthcare mission (CPR, 2017-) will provide information on cloud particles by operating at higher frequency of 93 GHz (W-band).
Beside active sensors, passive limb sounder such as JEM/SMILES (2009-2010) can provide data on upper-tropospheric ice water. A new instrument (SMILES-2) is currently under study which will also include a channel near 2 THz.

The measurements interpretation requires to take into account the multiple scattering (MS) of the radiation within the clouds. A model is being developed in NICT to study and quantify MS which will be applied for these instruments.

NICT current and future sensors

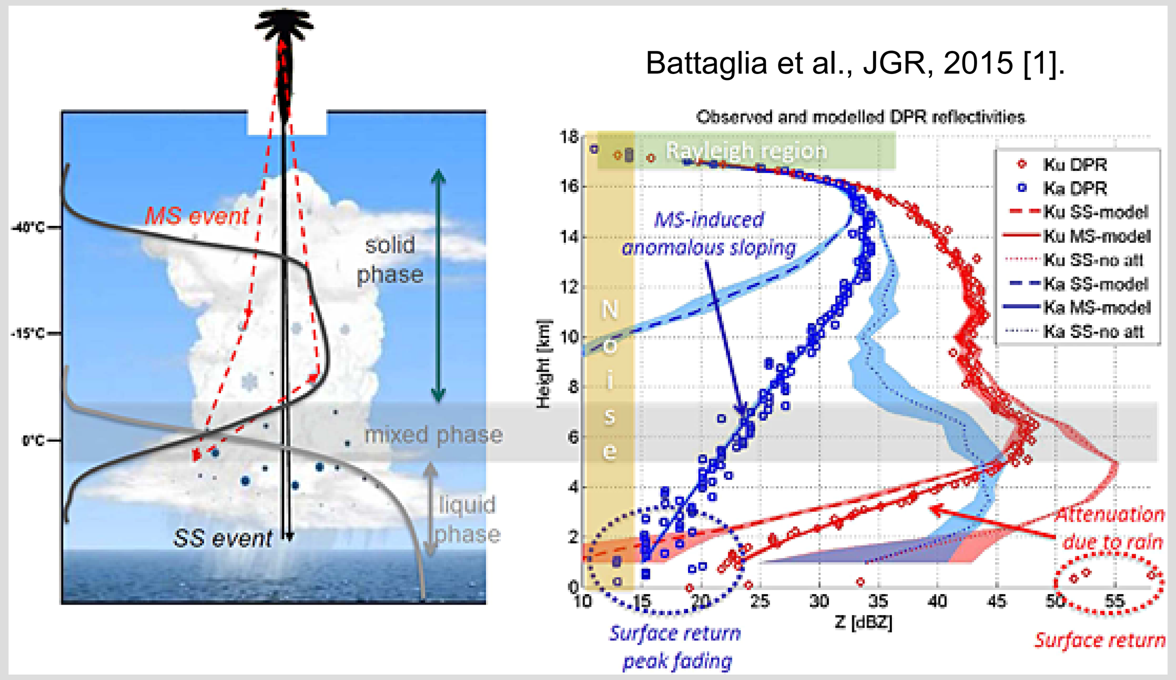
Active sounding

- GPM/Dual frequency Precipitation Radar (DPR)
  - 13.6 and 35.5 GHz (Ku- and Ka-band)
  - precipitating particles
- Earthcare/Cloud Profiling Radar (CPR)
  - 93 GHz (W-band)
  - cloud particles

Passive sounding
(Upper-tropospheric ice particles)

- JEM/SMILES, limb sounder, 2009-2010
  - 640 GHz
- SMILES-2, limb sounder, pre-phase A, 2025?
  - 640 GHz, 2 THz

MS on GPM/DPR



The figure hereabove is taken from [1]. It shows the impacts of MS within a strong convective cell on the Ka and Ku bands signals. Other evidences for MS effects have been found for an extreme convective condition [2] (ice core with particle sizes exceeding 2.5 cm and integrated ice contents exceeding 7.0 kg/m2).

[1] Battaglia et al.: "Multiple scattering in observations of the GPM Dual-Frequency Precipitation Radar: Evidence and impact on retrievals.", J. Geophys. Res. Atmos., 120, 4090–4101, 2015

[2] Battaglia et al. "Multiple-Scattering-Induced "Ghost Echoes" in GPM DPR Observations of a Tornadic Supercell", Journal of Applied Meteorology and Climatology, 55, 1653-1666, 2016

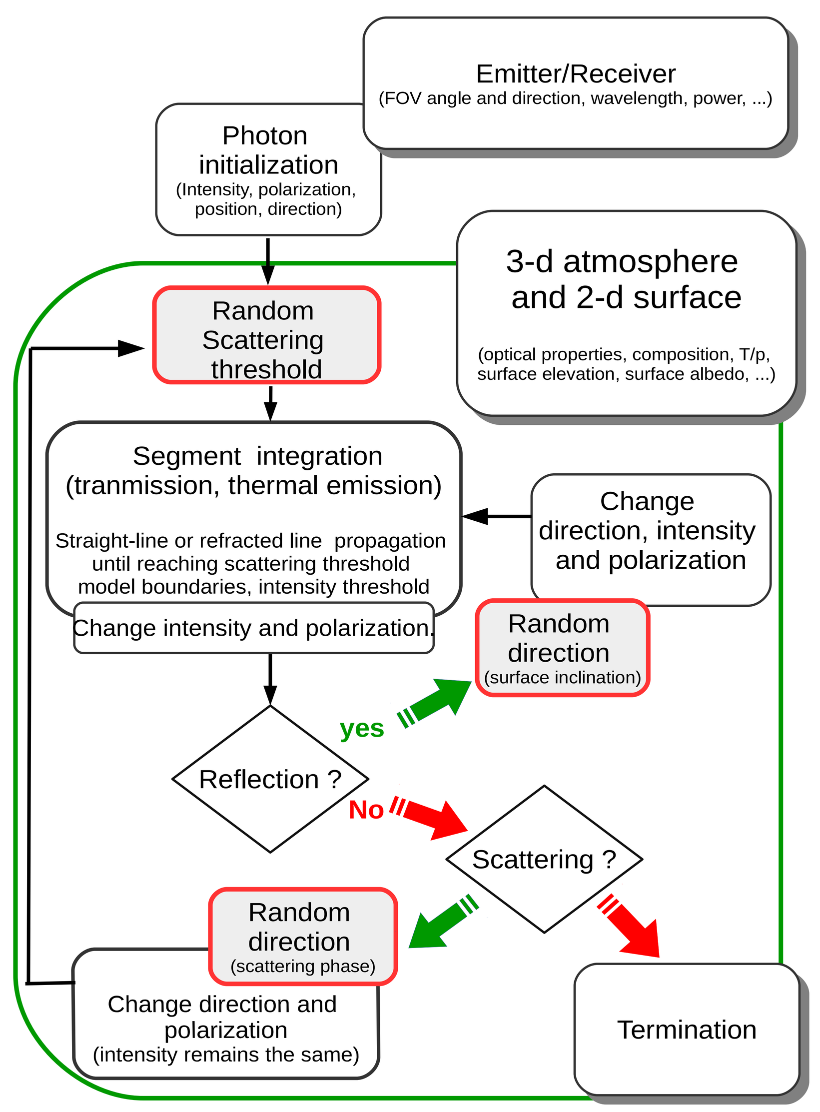
MS Radiative transfer (RT): A non-linear problem

$$\boxed{I(s,\phi,\beta)} = I(s_0)\exp(-\tau(s)) + \int_{\tau(s_0)}^{\tau(s)} [(1-\varpi_0)B_T(\tau') + \varpi_0\, j_{\rm sca}(\tau')]\exp(-\tau')\,d\tau' \quad (1)$$

$$j_{\rm sca}(s) = \iint_{4\pi} \Phi(\phi',\beta',\phi,\beta)\,\boxed{I(s,\phi',\beta')}\,d\Omega' \quad (2)$$

$$\iint_{4\pi} \Phi(\phi',\beta',\phi,\beta)\,d\Omega' = 1, \quad (3)$$

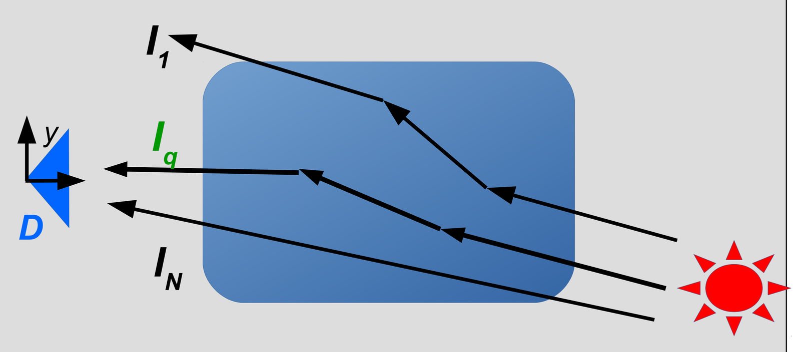
Model characteristics



Monte-Carlo solution

The problem is represented by N trajectories randomly generated according to the scattering and reflection properties of the medium.
Each trajectory is made of straight-line segments whose length is set by it scattering opacity value defined randomly.

The change of the radiation intensity is computing along each segment with non-scattering RT.
A scattering event induces the direction change between 2 segments which is randomly defined according to the local scattering phase function.
The Stockes vector describing the radiation intensity is rotated accordingly.

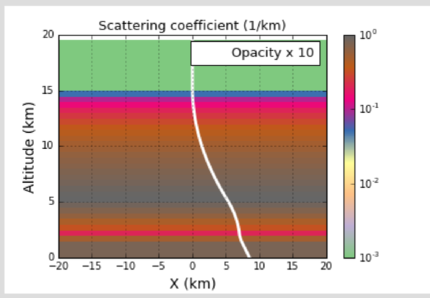


$$I_{\rm mc}(s,\theta,\phi) = \frac{1}{N\,\Delta_{yz}\,\Delta\Omega}\sum_{q=1}^{N_q} I_q(\mathbf{x},\mathbf{u}),$$

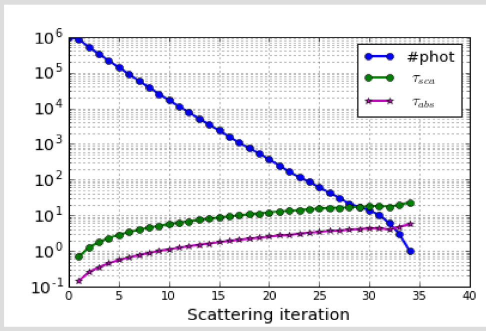
- Plane parallel for nadir geometry or spherical layers for limb geometry,
- The polarization state is described by the Stockes vector components (4 informations)
- Absorption and scattering by particles,
- Absorption by molecules using line-by-line and continuum models (e.g., Liebe 1993, ...),
- Thermal emission by molecules for passive sounder,
- Other characteristics: surface reflection, traveling time, Doppler shift, refraction for imb sounder.

Illustration with a simple test-case

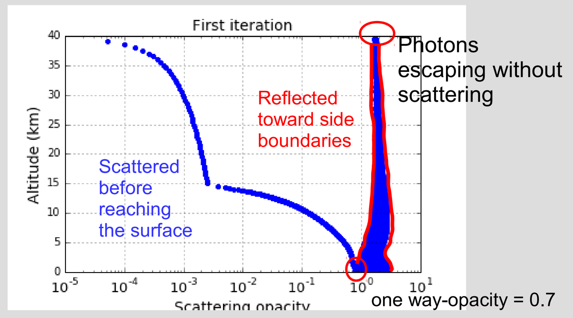
An homegeneous atmosphere is considered.
A vertical flux ofcollimated photons is sent downward from the top of the atmosphere (10^6 photons).
The photons propagate in a 3-D volume until they reach one of the vertical boundaries or escape from the top of the atmosphere. No stopping criteria based on intensity is used in this example (high absorption opacity allowed).
The scattering phase function is derived from from Mie theory .

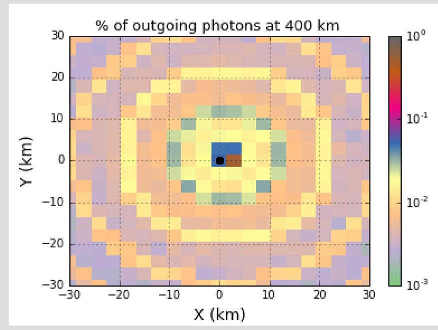


The one-way vertical opacity is 0.7-0.8



Photon altitude after the first iteration





The ripples are likely an artifact induced by the resolution of the phase function look-up table.

Status/Plan

- The model is still under development but can already be used for simulating radar observations.
- A first validation is performed solving simple cases with known theoretical solution (e.g., single scattering, …)
- Further validations will be performed for more realistic cloud conditions and with comparison with existing models.
- Analysis of GPM/DPR observations will be started after the validation of the main modules. The study will be performed in collaboration with NICT/PR team.